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Effects of amount of display structure and target duration on visual target detection.

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Introduction

The problem of visual search has long been recognized by the armed forces and also by many commercial institutions (aviation; navigation). According to Morris and Horne (14), field observations have shown that search procedures and patterns vary markedly without evident cause for such variation. Furthermore, while electronic devices constantly increase search potential, the information gained is still often transmitted to the human operator via a visual link.

In attempting to attack the problem of developing optimal visual search methods, a symposium (14) was held recently on visual search techniques. Several factors emerged from the focusing of diverse yet interrelated research in this area. In particular, it became clear that variable effects of observer search behavior and the structure of the search area are in critical need of further study. This experiment was intended to help fill this need.

Analysis of the problem

1. Structure of the visual field. A completely empty, homogeneous field may be defined as being at zero level of structure. As objects or contours are introduced into the field in increasing numbers, either systematically or randomly, the field may be said to increase in structure. When the visual field has no apparent fixed boundaries (e.g., arctic snow; sky at high altitudes; darkness) it

is considered unlimited as opposed to a limited visual field which is restricted by some physical perimeter (e.g., radar-scope; range finder). Several investigations have been concerned with the effects of structure or lack of it on search performance. Miller and Ludvigh (13) studies target detection in large homogeneous and partially structured fields. They found that observers became spatially disoriented over time, and, apparently due to absence of differential retinal stimulation, were unable to search systematically. Krendel and Wodinsky (11) investigated combinations of four target sizes, four search areas and four values of background luminance. Four contrasts were used for each of the sixteen target size and background luminance conditions. Four practiced observers performed for a total of 3072 search trials. The search areas were empty except for the targets. It was found, subject to certain restrictions, that plots of log percent targets detected vs search time could generally be fitted by a straight line. This relationship assumes a constant probability of detection for a single fixation, and that search is a series of independent fixations (i.e., search is random). Thus, for both unrestricted and restricted homogeneous fields, the above two studies suggest the absence of optimal or even systematic search on the part of observers.

There appears to be a gap in studies along the structure continuum between very large fields and relatively small fields. However, an experiment by Brody, Corbin, and Volkmann (5) dealing with "horizon-search" seems applicable as an intermediate step between the two extremes. These investigators used a semicircular, 30 foot radius, whote field which was 5 ft. high. The field had no visible microstructure. Targets consisted of 1/4 in. orange spots of light which appeared two ft. above the floor (horizon line) at any desired azimuth.. Search time was found to vary directly with angular search range and inversely with target brightness. When head movement was not permitted and subjects (Ss) were made to fixate a prescribed point during search, the effective (90-100%) detection range dropped sharply as target brightness was decreased.

Several aspects of the geometry and internal dynamics of visual displays have been investigated within more restricted search areas. Each aspect apparently plays a slightly different role in search performance. Erikson (8) used fields in the form of square matrices and varied (a) the number grid lines dividing the field, and (b) the number of irrelevant objects in the field. He reported search times to vary directly with both variables. He offered the hypothesis that increased search time was due to a greater required number of fixations as the complexity of the field increased. Baker, Morris, and Steedman (4) also found search time to increase with the number of irrelevant objects in the field. In a related experiment, Brody, Corbin and Volkmann (5) had Ss search for a particular symbol located within a rectangular matrix of symbols (e.g., triangle located within a matrix of circles). When median search time was plotted against matrix size ranging from 2 x 2 to 16 x 16 cells, a positive relationship was found. The curve consisted of two linear segments, with a pronounced increase in slope occurring over the range of matrices from 100 to 144 cells. The interpretation of this increase in search time suggested a critical matrix size, which implies that search method changes at some crucial point in display size and/or complexity.

2. "Natural" search patterns and biases. The possible existence of persistent characteristic search methods which are independent of display variables has also been the subject of several investigations. Enoch (6) recorded the eye movements of experienced photo-interpreters who viewed aerial photographs which varied in scale and verticality. He also recorded the eye movements of inexperienced observers who viewed simulated aerial photographs. In both cases the distribution of eye fixations was found to be markedly concentrated at the center of the display whereas the peripheral regions were largely ignored. This result was independent of the display quality, size, content and experience of the observers. Furthermore, eye movements were distributed in a variety of systematic patterns, all of which had in common two general phases; (a) and initial or orienting phase described as spiral (inward or outward), up and down, laterally back and forth starting at either the top or bottom, a closing square pattern, etc.; (b) a search phase which utilized what were interpreted by observers to be cues, or if no cues existed, a search phase which was an expansion of the initial pattern. Regarding the use of cues, Baddeley (1) found that Ss oriented their search around irrelevant objects in the field and were thus distracted from some better method

of search. In a supplemental study concerning the effects of the size of complex displays on visual search, Enoch (7) found that visual coverage of the displays was not uniform. In particular, fixations were concentrated in the center of the display. For smaller displays, marked differences were noted. As the size of the display increased up to 9°, durations of fixations decreased, interfixation distances increased, concentration of attention in the central area decreased and efficiency (defined as the percent of eye fixations falling within the display area) decreased. No further change in these characteristics was observed for displays subtending 9° or more at the eye. Ford, White and Lichtenstein (9) recorded eye movements and frequency of fixations on a 30° empty field. They reported a concentration of fixations within a 5° - 15° band inside the 30° field. Thus both the center of the display and the periphery were neglected under these search conditions. The rate of fixations was found to be about 3 per sec. and fixation duration was about .25 sec. In a subsequent study, White and Ford (18) found that introduction of a radial sweep line altered the search pattern. In this situation Ss tended to track the line except for periodic saccadic excursions. This was taken to demonstrate that search behavior is related to the internal dynamics of the display.

3. Observer-display interaction; search strategy. With regard to studies of search patterns, it is possible to conceive of the search situation as being a product of the joint effects of observer and display variables. This was proposed by Teichner (16) who suggested that the problem be viewed as an interaction in the sense that search per-

formance depends both on the potential search strategies of the observer and the restrictions placed on such strategies by the search media. Accordingly, systematic search may not be possible in the absence of visual reference (Miller and Ludvigh, 13) or when inherent biases are evoked by particular display characteristics (Baddeley, 1).

Several methods for reducing search bias and inducing more systematic coverage of displays have been studied. Among these are automatic scanning devices which move through a prescribed search pattern and are followed visually. Townsend and Fry (17) evaluated an automatic scanner which moved a small circle over the display. Observers, instructed to keep their attention within this circle, demonstrated better target detection than they did with free search, at least for low contrast targets. However, high contrast targets were detected peripherally even before the scanner was turned on. Another type of scanning device was investigated by Baker (2). Target detection was significantly increased by having observers search the outer half of a simulated radar screen during the interval that a green light was on. In a further study by Baker and Boyes (3) an existing central search bias was capitalized on by designing a B-scanner (square radar-like screen with vertical sweep line) so as to make normally peripheral events occur centrally.

Another approach to the display strategy problem was used by Gottsdanker (10). He investigated the relation between the nature of the search situation and the effectiveness of alternative strategies of search. Two search situations were used, one characterized by "competition" (search objects plus similarly constructed distractors), the second characterized by imbededness (search objects dissimilar to background but with "background broken up so as to make search difficult"). Under each situation a comparison was made between performance which required a specific search strategy and free search. For the specified strategy, Ss were instructed to find all objects in a particular class before going on to the next class (sequential search). With free search no restrictions were placed on Ss' search methods or the order in which they were to find the search objects. The latter was found to be superior in both the "competition" and "imbededness" situations.

In view of the diverse evidence relating to display structure and target detection, Teichner (16) has suggested that certain kinds and quantities of structure may be more effective than others in inducing search patterns. He noted further the importance of future studies which attempt to relate the geometrical factors of the display to the observer's search strategy and the final target detection level. In this regard, a study by Reilly and Teichner (15) was performed as an initial step toward the determination of possible systematic relationships between target detection and location, and display geometry. This study tested the effects of two general forms of search area, circular and square, five levels of structure of search area where structure was defined as the subdivision of the search area by means of contours and search times of three, six, and nine seconds.

The experimental structures were of two types, concentric circles for the circular field and vertical grid lines for the square field. These were chosen in accordance with their similarity to the natural search patterns reported by Enoch (6). In general it was found that target detection was better for square search fields, intermediate levels of structure and longer search times. However, the advantage of square fields over circular fields tended to decline at both the longest search time and at the highest level of structure. The data suggested an optimal level of structure defined by the division of the search field into three equal area partitions.

From the studies reviewed it appears that Ss exhibit unsystematic and biased search behavior which results in non-uniform display coverage. In particular, several relationships are apparent between time to detect targets and various display factors. With large empty visual fields search is apparently unsystematic. As the field becomes smaller or more restricted, "natural" search patterns can be observed which appear to be independent of display characteristics. These patterns, however, exhibit biases in attention such as a concentric of fixations in the central portion of displays. As display complexity increases (complexity defined by number of irrelevant objects in the field or contours dividing the field) detection time is found to increase. Furthermore, as irrelevant objects appear in the visual field, they are often interpreted by Ss to be cues. This leads to a biasing of search toward the "cues" with consequent neglect of the rest of the display.

<u>Purpose</u>

The literature reviewed indicates an important need for further investigation of several aspects of the search, display-geometry relationship as they may influence target detection. In particular there seems to be a need for systematic information about the relationship between target detection and type and complexity of display structure. The purpose of this study, therefore, was to investigate these variables.

Since no studies are available which have treated structure over a wide range from a large, unrestricted area to a highly complex area, the relationship between target detection and amount or complexity of display structure was a major interest. With an unlimited, homogeneous search area (zero structure) the only restriction imposed on search at any instant is the observer's own field of vision. However, the dimensions of a restricted search area may be well within those of the observer's visual field. As structure is increased from zero (unlimited, homogeneous area) by the introduction of contour lines which define the search area, the required search area is reduced. Further, the presence of lines or objects in the field tends to restrict search and produce biases in search performance (Baddeley, 1). Since detection varies inversely with size of search area (4, 8) it can be deduced that the initial structure lines will improve performance. Further subdivision into smaller areas might increase detection still more up to some limiting number of cells (Reilly and Teichner, 15). The present study investigated this deduction and tested the hypothesis that the introduction of increasing amounts of structure into a large homogeneous field would initially produce an improvement in detection performance, but, as the search area became more complex, a reversal would occur with poorer performance occurring at the higher levels of structure.

A further aim of this study was to extend information concerning the relationship between target detection and target duration particularly with respect to a possible interaction with display structure. The execution of strategies suggested or induced by particular kinds and amounts of display structuring would seem to depend in part on the time available to the searcher. This expectation was evaluated as a test of the hypothesis that levels of structure would interact with target duration while detection would vary directly with target duration.

An additional interest in the use of structure lines in visual displays concerns the orientation of these lines. Previous studies have not treated this factor parametrically. For example, Reilly and Teichner (15) used only vertical lines. Erikson (8) used horizontal and vertical lines simultaneously to produce structure in the form of a grid. Brody et al (5) investigated displays of symbols in matrix form with the structure lines formed by the rows and columns, again in the form of a grid. Since no systematic information is available regarding the effects of position of simple structuring (e.g., straight lines running in a single direction) the present study was designed to obtain such information. As an initial step regarding this variable, this experiment tested the effects of vertical vs horizontal structure lines. In the absense of relevant experimental data relating to structure line orientation a specific outcome was not predicted.

Method

Subjects.--The 64 subjects (Ss) were 38 male and 24 female undergraduates enrolled in the summer school at the University of Massachusetts. Each S was paid one dollar for participating in the experiment.

Apparatus.--The apparatus consisted of a slide projector and slides, a programmer, an Esterline-Angus multi-channel event recorder, four silent push-button switches. The targets were transmitted through a 4 x 4 ft. piece of frosted glass backed by plywood painted flat black. Holes in the plywood allowed for presentation of 1/4 in. circles of light (targets) in 85 positions over the surface of the target mount (screen) by means of rear illumination. A 6 v d.c. lamp was mounted behind each hole. These targets subtended 9 min. of visual angle at a viewing distance of 8 feet. Targets were .68 candlepower in intensity. The 6 v lamps were operated on 1.5 v and therefore the targets were orange in appearance. The screen was mounted on a black wooden frame such that the center of the screen was 49 in. from the floor, approximately at eye-level with seated observers.

The programming device was a rotating metal drum which had 90 piano wire contacts riding tangent to it. Each contact represented one of 90 parallel circuits. When a wire touched the drum a circuit was completed. By covering the drum with oilcloth and punching holes of the appropriate size and at the proper intervals, it was possible to program a wide range of events with the 90 circuits. The programmer was equipped with a panel of telephone jacks such that apparatus could be connected simply by inserting telephone plugs.

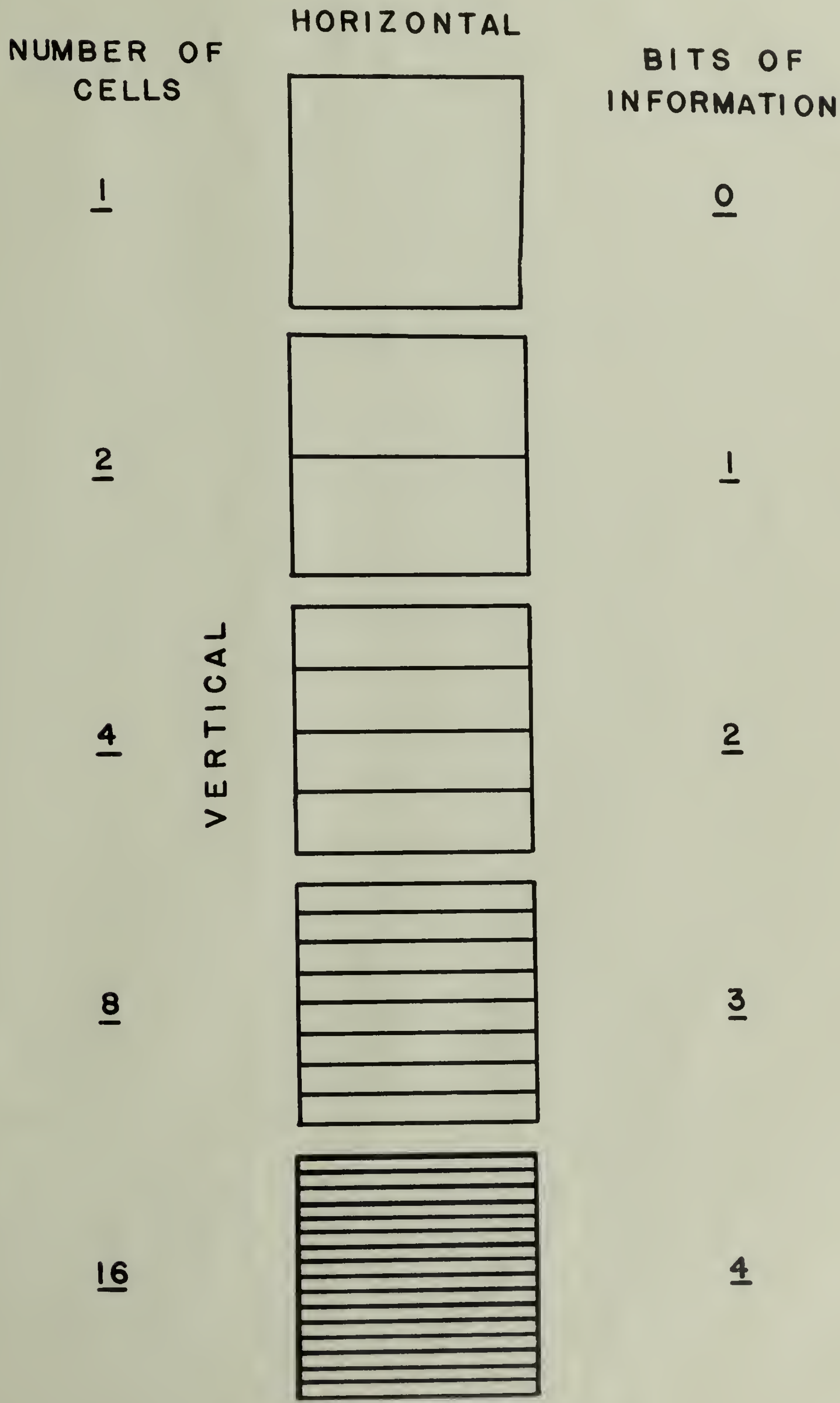
The programmer and silent switches were connected to indivdual channels on the recorder. When a S pressed his switch it was registered on his particular channel. When a target occurred on the screen it also was recorded on a separate channel.

Five negative slides were made by photographing black-on-white drawings of the structures. These provided white images when projected onto the dark screen. The experiment was performed in a dark room.

A continuum of search area structure from low to high was achieved by the use of (a) totally dark room with no visual reference; (b) point source of red light within the dark room provided by a 5/16 in. red jeweled lamp at the top center of the screen; (c) five restricted displays which increased in structure by progressive subdivision into two, four, eight and sixteen equal area partitions. The restricted displays were 4 x 4 ft. projected images. These structures were presented as vertical lines or as horizontal lines by simply rotating the slides 90°. Thus the dark room, dark room with red light and the five slides constituted seven structure conditions of increasing complexity. The structures defined by the slides are presented in Fig. 1. The number of cells or partitions is listed next to each structure. The amount of display information in bits is also presented for each structure. Information is defined as the logarithm to the base 2 of the number of cells in the display.

Twenty-four of the original targets available on the screen were eliminated because they were located so as to appear directly under

Figure 1. Structures presented by means of slides. Number of cells and amount of information is shown for each display. Seen by Ss as light images on dark surround.



one or more of the various structure lines. Seven sets of 10 targets each were selected at random from the 61 remaining targets. The sets of targets were examined to insure that they did not by chance fall in some obviously systematic pattern such as a row, column, cross, etc. They were also checked for uniformity of distribution over the display. Should all or most of any set of targets have fallen within a small segment (e.g., a single quadrant) evaluation of the corresponding structure would have been impossible. However, no changes were required of the originally selected targets.

Procedure

Ten preliminary Ss not serving in the experiment were used to establish a target intensity which was well above absolute threshold under dark adaptation but dim enough so as not to be immediately detectable peripherally. The target intensity was determined to be .68 candlepower. The procedure for determining this intensity was similar to that used in a previous study by Reilly and Teichner (15).

All Ss in the experiment were given four test targets to insure visibility for each individual. All Ss reported that the targets were easily visible although it was necessary for some that the target location be pointed out before they acknowledged seeing it.

The 64 Ss were assigned at random to eight equal groups. Eabh group represented a treatment combination of target duration and structure line orientation (horizontal vs vertical). Target durations were 5, 10, 20 or 40 seconds. Each group of Ss was presented 10 targets in random sequence under each of the seven structure conditions. The totally dark room was always the first search condition and the dark room with point source of light was always second. This was a necessary requirement since under the other search conditions there was enough light for the Ss to determine the limits of the display. It was desired that such knowledge not be available as a possible influence when searching under the unrestricted conditions. The remaining five structure conditions were presented in either of two counterbalanced sequences so as to minimize order effects. Subjects performed in groups of four. The first four in each treatment group received the structure conditions in the order: 0, 2, 4, 3, 1, where these numbers refer to bits of information in each projected display. The second four Ss were presented the displays in the order: 1, 3, 4, 2, 0.

Each S was blindfolded, led into the experimental room, seated in a chair 8 ft. from the screen and handed a silent push-button switch. The room lights were turned off and Ss were asked to remove their blindfolds. A 15 min. dark adaptation period followed during which instructions were given. After this Ss were tested with four preliminary targets not used in the experiment. Ss were instructed to search continuously for targets which would occur somewhere in front of them. Each was to report detections by pressing his switch. When the search area was determined by the slides, Ss were informed that all targets would occur within the perimeter of the projected image. A copy of the instructions is included in Appendix A.

Results

The dependent measure was percent targets detected. This was based on a possible total of 10 targets per S under each treatment combination. Means and standard deviations of these measures are presented in Table 2 in Appendix B. Fig. 2 presents mean percent targets detected as a function of amount of display structure with target duration and structure orientation as parameters. The first point on the abscissa represents the totally dark room (D). The second point represents the dark room plus the red point source of light (L). The remaining five points are amounts of structure in bits as shown in Fig. 1. The dark room and red light conditions represent a logical downward extension of the structure dimension but are not amenable to the information measure as defined above. The values for these conditions, therefore, were included for purposes of comparison but were left unconnected. The variable of structure line orientation (horizontal vs vertical) was present only in the highest four structure conditions since the dark room, dark room plus red light and the unpartitioned square did not contain structure lines. The values shown for orientation under the first three conditions merely indicate differences among subject groups. An analysis of variance was performed on the data summarized in Fig. 2. The results of this analysis are shown in Table 1. As seen in Table 1, the effects of Structure, Target Duration and the interaction of Structure with Target Duration were significant at $p < .01$. The nonsignificant effects were Orientation and the interactions of Orientation x Target Duration, Orientation x Structure and Orientation

Figure 2. Mean percent targets detected as a function of display information with target duration and line orientation as parameters.

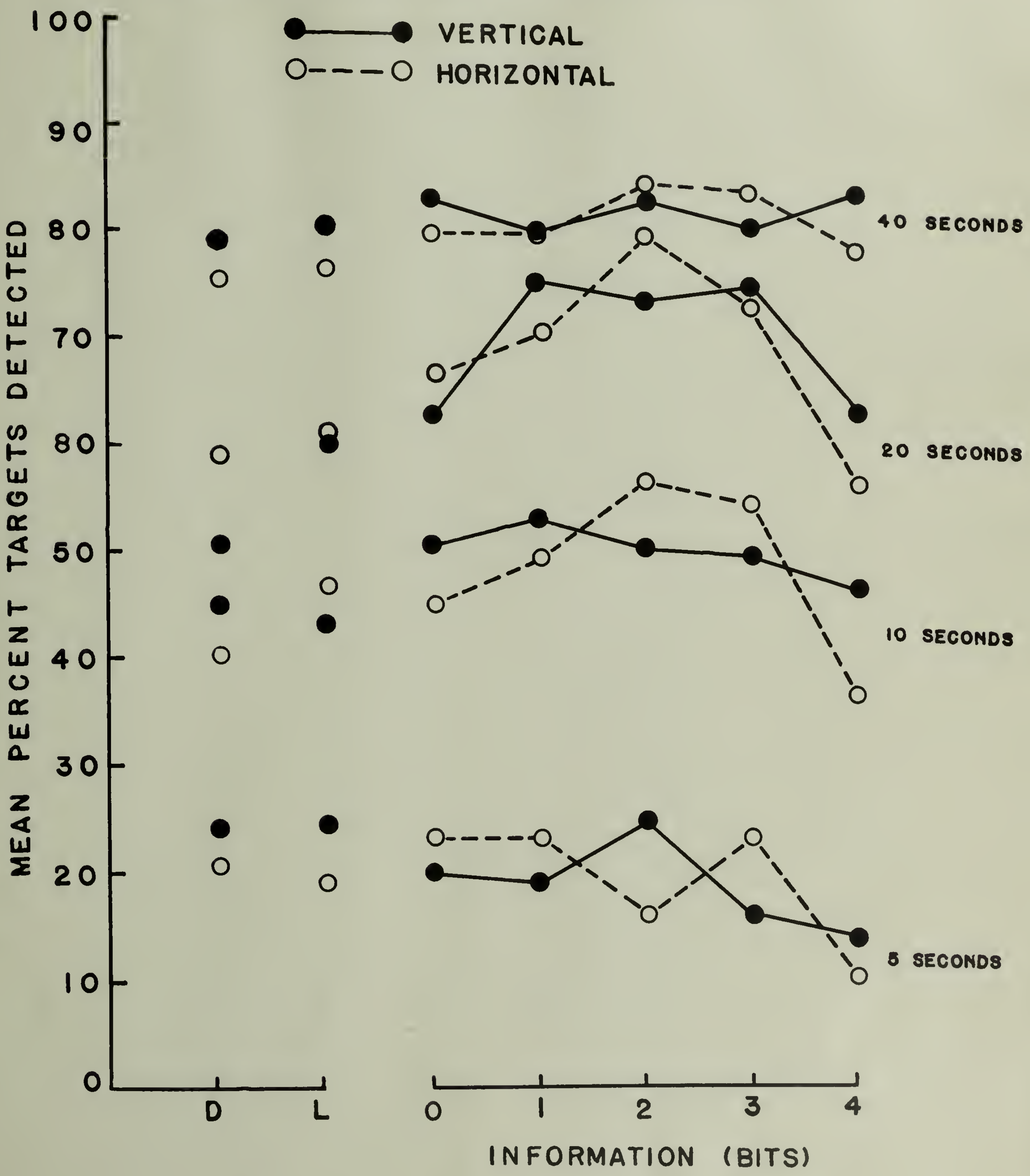


Table 1

Summary of Analysis of Variance on Percent Targets Detected

Source of Variance	df	MS	F
Orientation (O)	1	0.43	.076
Duration (D)	3	781.55	139.81**
O x D	3	0.39	.069
Ss/O x D (error)	56	5.59	
Structure (S)	6	10.41	14.46**
S x O	6	1.14	1.58
S x D	18	2.53	3.51**
S x O x D	18	0.97	1.35
Ss x S/O x D (error)	336	0.72	

** $P < .01$

x Structure x Target Duration. The analysis on the complete data increased the probability of accepting a false null hypothesis regarding structure line orientation. The complete data included scores from conditions in which this variable was not represented and thus contributed only to the error variance. Further statistical analysis was performed on the data for the 1, 2, 3, and 4 bit conditions to evaluate the effect of Orientation. The results of the restricted analysis are shown in Table 3. The effect of structure line orientation was still non-significant ($F < 1$; df 1, 56). Since the effect of Orientation was neither systematic nor statistically significant the data were pooled across Orientation and replotted as in Fig. 3 to provide clearer graphical representation of the other effects. Inspection of Fig. 3 shows that the curves for each target duration do not overlap at any point. Although the curves for 5 sec. and 40 sec. appear flat the curves for 10 and 20 sec. suggest an upward trend to a limiting value of 2 bits (four partitions) followed by a reversal or downward trend over the higher structure conditions.

Fig. 4 presents target detection as a function of structure. Inspection of this figure shows 2 bits to be the condition of highest detection (59%). Changing values of structure in both directions from 2 bits are associated with decreasing detection. The form of the data in Fig. 4 in conjunction with the statistically significant structure effect strongly suggests 2 bits as the limiting amount of structure for this search situation. With regard to Fig. 3, the differences in form among curves is attested to by the significant interaction of Duration

Table 3

Summary of Analysis of Variance on Percent Targets Detected for 1, 2, 3 and 4 Bit conditions

Source of Variance	df	MS	F
Orientation (O)	1	.39	-
Duration (D)	3	503.64	14.76**
O x D	3	.06	-
Ss/O x D (error)	56	34.13	
Structure (S)	3	13.27	10.97**
S x O	3	2.29	1.87
S x D	9	1.37	1.13
S x O x D	9	1.09	-
Ss x S/O x D (error)	168	1.21	

$^{**}P < .01$

Figure 3. Mean percent targets detected as a function of display information with target duration as the parameter.

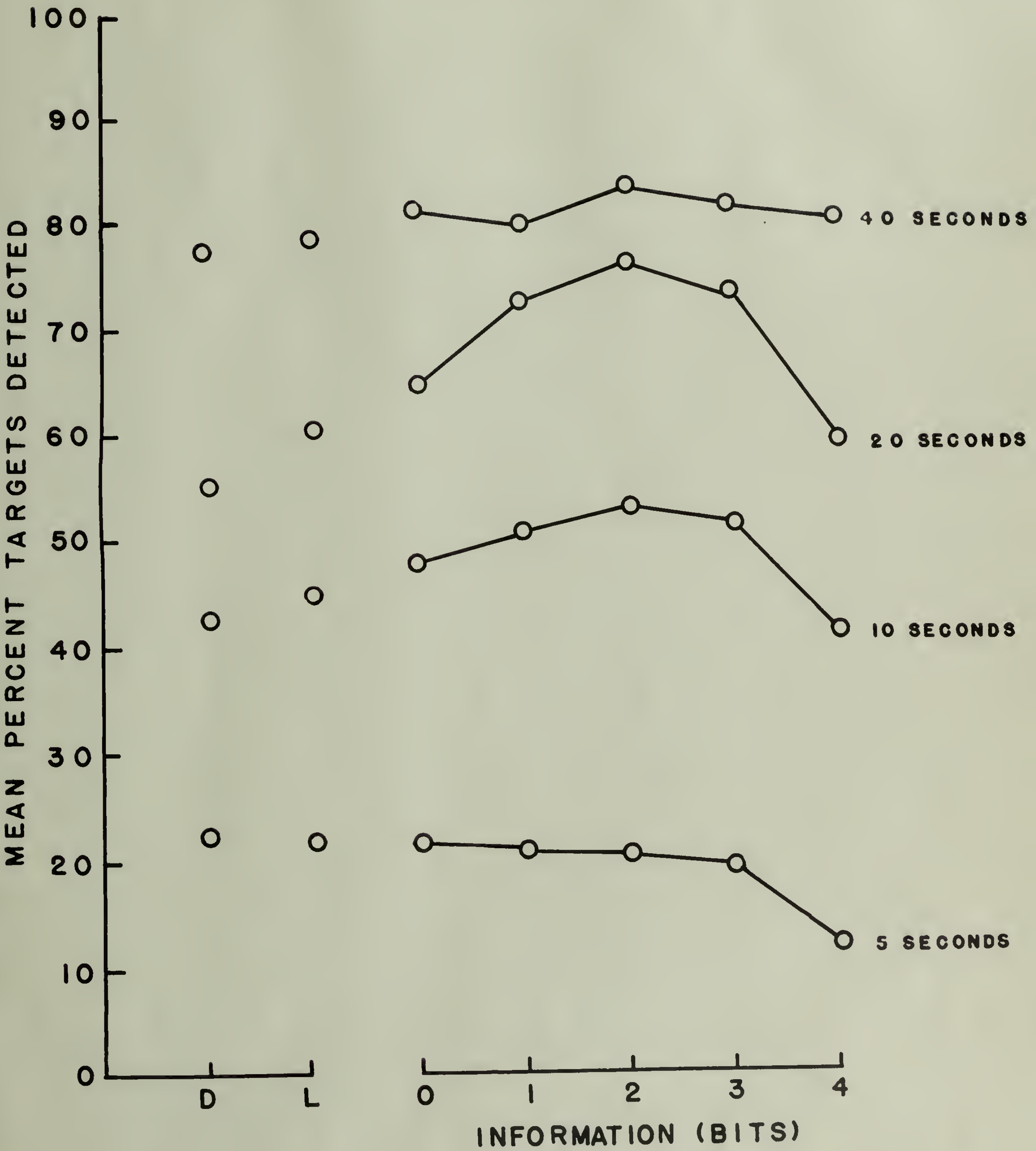
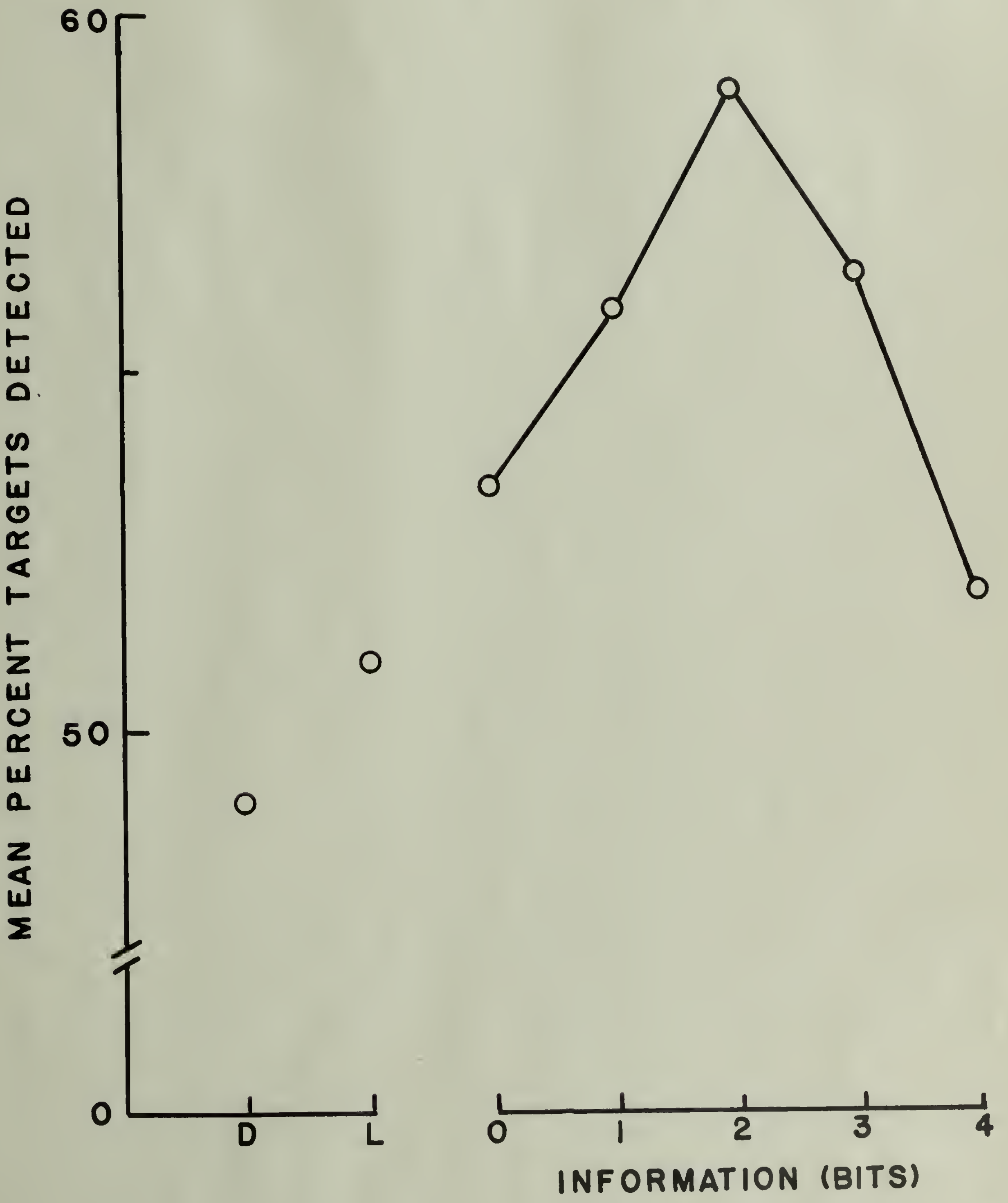


Figure 4. Mean percent targets detected as a function of display information.



with Structure. This indicates that the magnitude of differential structure effects depends upon target duration. The basis for the significant interaction appears to lie in the observation that structure effects are greater for the 10 and 20 sec. conditions and are negligible for the 5 and 40 sec. conditions.

As a supplementary evaluation of the significant Duration x Structure interaction a Least Significant Difference Test (L.S.D.) was performed on the means plotted in Fig. 3. The results of the L.S.D. test are summarized in Table 4. The means in the table are in rank order. Means which are not significantly different are underlined. The values which are not underscored by the same line are significantly different from each other at $P < .05$. From inspection of the table, it is apparent that the differential effects of structure are greater for the 10 and 20 sec. conditions.

Fig. 5 presents mean percent targets detected as a function of target duration. It may be seen in this figure that detection is a negatively accelerated increasing function of target duration.

Table 4

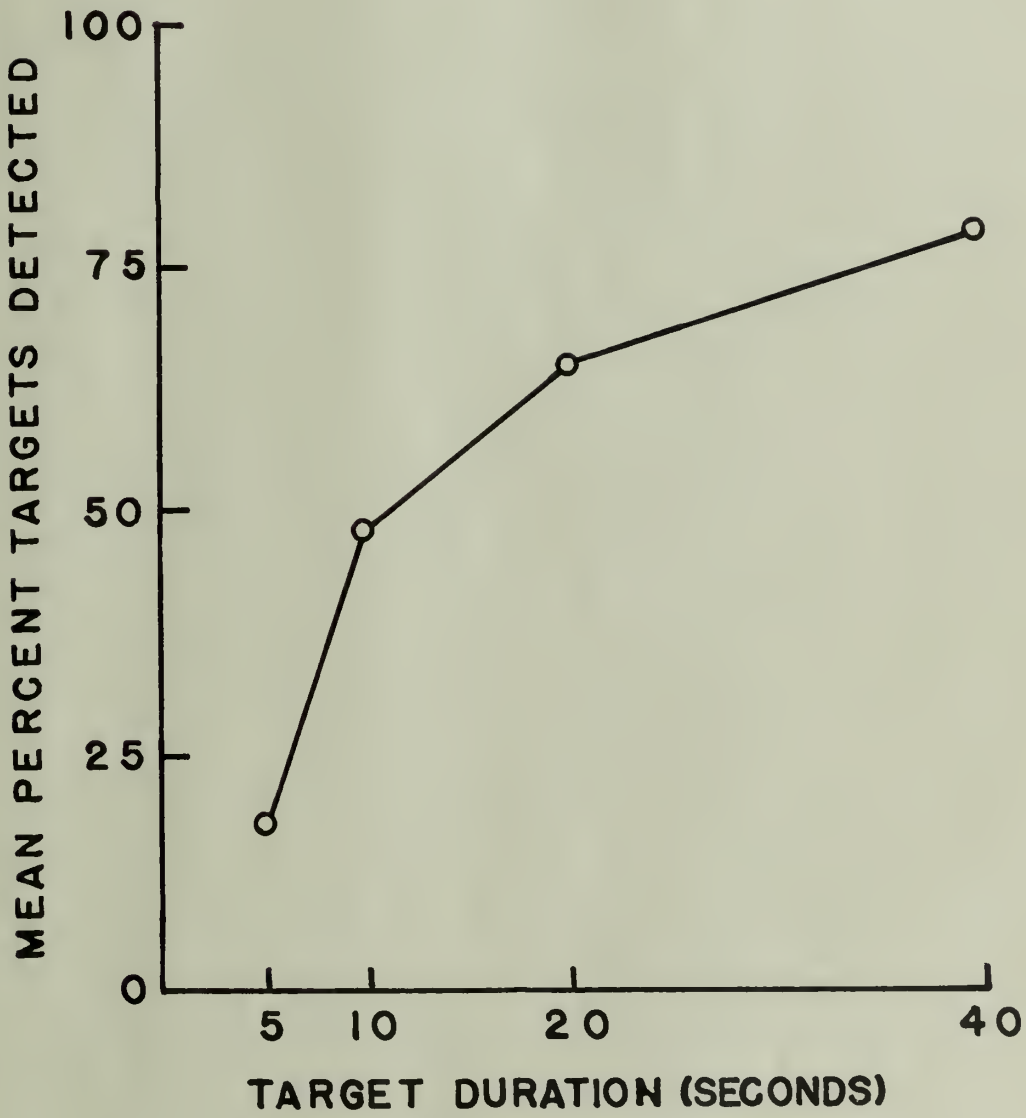
Summary of Results of

Least Significant Difference Test

Target Duration (Seconds)	Ranked means of Percent Targets Detected for each Structure x Duration Cell						
40	77.5	79.0	80.5	81.5	81.5	82.5	84.0
20	55.0	60.0	60.5	65.0	73.0	73.0	77.0
10	42.0	42.5	45.0	48.0	51.0	52.5	54.0
5	12.0	20.0	21.0	21.0	21.5	21.5	22.5

L.S.D. = 1.87

Figure 5. Mean percent targets detected as a function of target duration.



Discussion

One hypothesis of the present study was that for the range of structure investigated, target detection would increase up to some limiting degree of complexity after which it would decrease. The results appear to support the hypothesis at least for intermediate target durations. The data suggest two bits as the limiting degree of complexity, i.e., subdivision of the search display into four equal area partitions. An explanation of the structure function, which exhibits the predicted increase in detection and its subsequent decline over the higher levels of complexity, would seem to require both increment and decrement-producing factors. The increase in detection from zero structure to two bits concerns two underlying elements. The first concerns the introduction of the red light into the unstructured field followed by the projection of the empty square which completely delineated the search area. These two conditions may be seen as consecutive reductions in search area relative to the unstructured dark room. Since detection has been found to vary inversely with search area (Baker et al, 4; Enoch, 7; Erikson, 8; Krendel & Wodinsky, 11), it seems reasonable to assume that a similar effect is present here. The increment in performance produced with higher display complexity by subdivision of the square up to two bits does not constitute a further reduction in search area. Therefore, the second explanatory factor is necessary. With the empty display, only the perimeter itself was present to affect search performance. Beyond the influence of these boundaries there were no objects or contours in the area to influence search behavior.

Evidence from several studies (Miller & Ludvigh, 12; Baker & Boyes, 3; White & Ford, 18) is related to why the partitioning of the display might produce an increment in detection. With a limited search area, performance is related to the internal dynamics of the display. The only previous study which used more than a single level of structure was that by Reilly and Teichner (15). They found that partitioning of a 452 square in. search area into three equal areas resulted in improved detection. In that study, Ss reported that their search performance was influenced directly by the structure lines. If target detection is observed to be better in the presence of structure lines than without them, it seems plausible that search might be more systematic under the structured conditions. A suggestion which was offered by Reilly and Teichner seems applicable here. This includes two possible reasons for improved performance. One is that the presence of structure lines tends to counteract such bias as a concentration of fixations in the center of the display. The second factor is that structure lines provide cues which may be utilized in remembering which parts of the display have been searched and which have not. Eye movement data from several studies (Enoch, 6; White and Ford, 18; Ford, White & Lichtenstein, 9) indicate that visual coverage of unstructured displays is biased and unsystematic. Unfortunately, no data are available relating eye-movements to systematic variations in display structure and complexity. This would seem to be an important next step in the search strategy display-geometry relationship.

With regard to decrement-producing factors underlying the decline in performance beyond some optimal degree of structure, an important consideration seems to be the extent to which display compartments can be discriminated and searched. In a related study, Erikson (8) investigated displays in matrix form which ranged from 9 x 9 to 16 x 16 cells. He found that search time increased with the number of cells. In relation to the study by Reilly and Teichner (15) and the present results it might be suggested that even for the largest display used by Erikson (8) which was 964 square in., 81 cells represented a degree of structure far beyond that which would be of benefit in terms of search strategy. The implication is that as structuring increases beyond some optimal level for a fixed overall display area, the partitions may become too numerous and too small to be of assistance in achieving uniform display coverage. If the partitions are too numerous to be searched easily and eliminated without a high probability of researching the same ones, or if they are so small that single fixations tend to overlap several cells, then the benefit gained from the use of structure lines would be lost. While the fact that there is a reversal in performance as structure increases has been demonstrated both in the present study and a previous one by Reilly and Teichner (15), and that if the initial degree of structure is high, further increase in structure only produces a decline in performance (Erikson, 8), the exact search patterns and distribution of eye fixations relative to these conditions remain to be investigated.

The results indicate that the effect of structure depends on the target duration. The differential effects of structure appeared to be most pronounced for durations of 10 and 20 sec. At both the shortest

(5 sec.) and longest (40 sec.) durations investigated, the effects of structure appear to be minimized. Regarding the 40 sec. condition it seems reasonable that even with inefficient searching there was ample time to detect enough targets to minimize any benefit achieved by some more systematic search method. Although the structures may suggest different strategies, 5 sec. may be insufficient time in which to execute them. Again, differential effects afforded by structure would not be manifest here. Thus, while the overall structure effect, independent of target duration, is significent, the structure by duration interaction suggests that the relative enhancement of performance through the use of structure depends upon the target duration. A similar effect was found by Reilly and Teichner (15) where structure effects were dependent upon search time. In that study, onset of target and display contours were simultaneous thus equating search time with target duration.

Target detection was a negatively accelerated function of search time ranging from 19% detection at 5 sec. to 81% detection at 40 seconds. These results are consistent with Reilly and Teichner (15) who also reported decreasing gains in detection with increased search time for square displays.

The flattening of the structure curve at 40 sec. suggests that relatively little further gain in performance due to the differential effects of structure would have been obtained with longer search times. However, while each target was above threshold for all searchers, caution should be exercised in extrapolating the present data to the

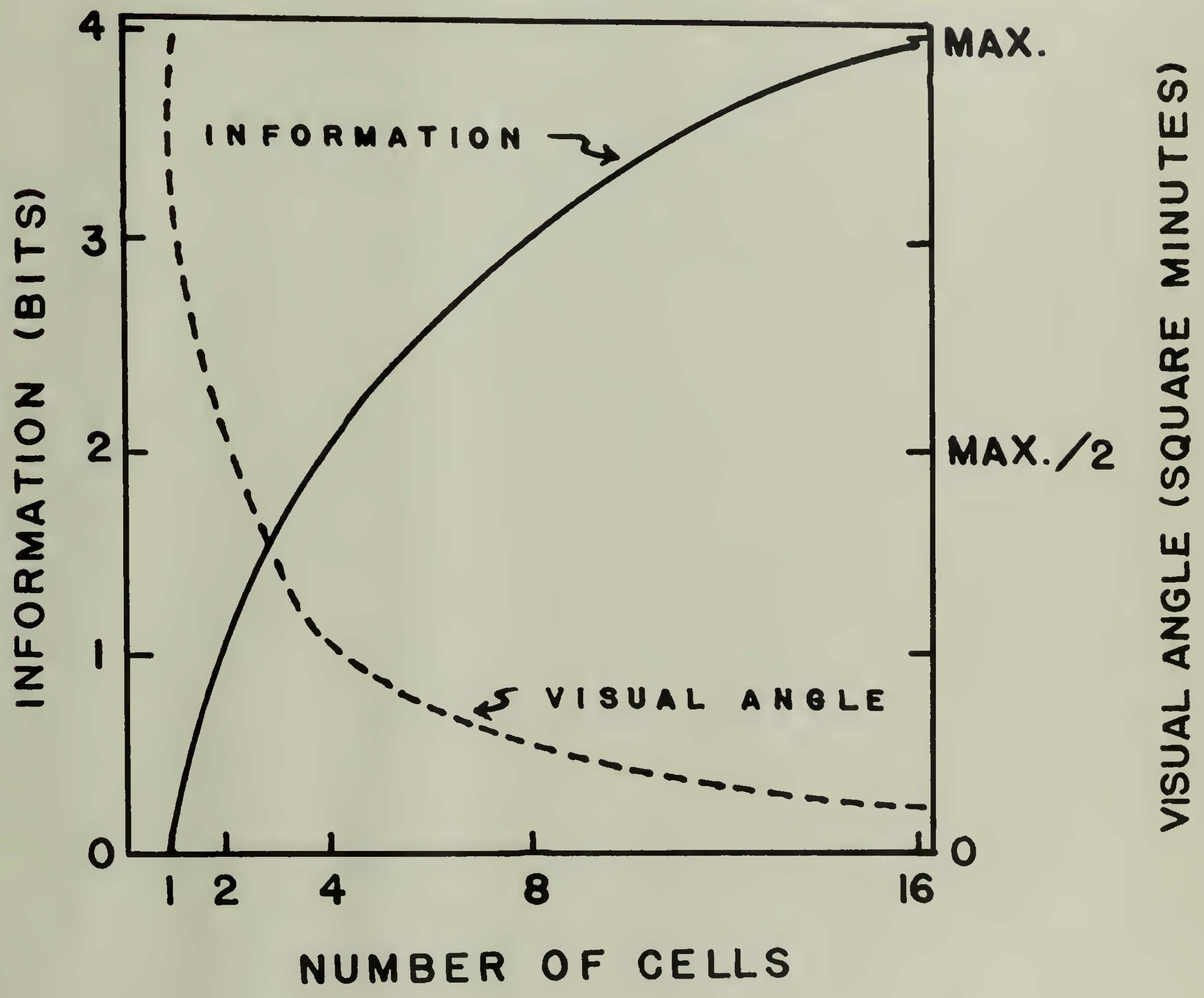
80-100% detection range. A further study seems necessary in which time required for 90% or 100% detection would be the dependent measure.

Regarding the orientation of structure lines (vertical vs horizontal) further information appears essential before drawing conclusions about the absence of this effect. Incidental verbal reports from Ss in the present study were in agreement with the results of a questionnaire used by Reilly and Teichner (15). In that study Ss expressed a preference for a particular manner of search regardless of display structure. That is, those Ss who preferred to search with a series of vertical sweeps reported doing so even in the presence of horizontal structure lines. It would be valuable to investigate the search strategy display-structure problem further by classifying searchers according to preferred search patterns and comparing their performance using structures which coincided with preferred patterns and structures which did not. It might be expected here that Ss who had structures corresponding to their preferred patterns would do better than those who had to search across structure lines instead of with them. Since, in the present study, preferences presumably existed randomly within groups of Ss exposed to either vertical or horizontal structure lines, the above effects, if present, would tend to be cancelled. This could possibly result in a non-significant difference between horizontal and vertical structure lines.

In attempting to describe the amount of structure characteristic of a display, the number of cells and amount of information associated with displays are two common metrics used. Unfortunately, neither of these takes direct account of the visual angle of the search area. Available studies specify number of cells and viewing distance independently and do not consider their interactions relative to other possible metrics. For some types of display, solid visual angle may be an important characteristic of the structure present. This is illustrated in Fig. 6 which shows the relationship among three display structure metrics. This figure shows both amount of information in bits and cell visual angle (square min.) as a function of the number of cells in the display. Since information is a logarithmic transformation of the relative frequency of cells, the relationship is a negatively accelerated exponential function. Visual angle is seen to be equal to the reciprocal of the number of cells multiplied by the total visual angle subtended by the display. Since visual angle and number of cells are inversely related for any fixed overall display area, visual angle is also inversely related to the amount of information associated with the display.

As displays vary in size, shape and complexity, the problem of relating search strategies to visual displays becomes increasingly difficult. While further investigation along the present lines might be carried out fruitfully, it seems that the next step would require eye-movement data. Evidence of the relationships among frequency, distribution and patterns of eye fixations and various types of display structures could be obtained directly with such data rather than by inference from detection performance as in the present experiment. Studies such as those by Mackworth and Mackworth (12), Enoch (6), and

Figure 6. Display information and cell visual angle as a function of number of display cells.



White and Ford (18) constitute a step in this direction. However, none of these has treated structure over an appreciable range. Consideration of the results of the present study suggests the following conclusions:

1. For visual displays in which low contrast targets appear against a homogeneous surround, increasing the structuring up to some critical amount appears to produce an improvement in target detection. Additional structuring beyond this seems to account for a decrement in performance. While the hypothesis seems tenable that structure lines provide the basis for systematic modes of search which are not applicable under unstructured conditions, eye-movement data would be of great value in determining the specific search patterns which various kinds and amounts of structure may induce.

2. The extent to which the relative enhancement in performace may be derived from the use of structure depends upon the target duration. The present results suggest that differential effects due to the amount of structure may be minimized either if there is too little time to execute a search strategy or if there is so much time that almost any type of search would eventually find the target.

3. Target detection is directly related to target duration and for the conditions tested and the range of time used in the present study, increased duration provides decreasing gains in target detection.

4. A comparison of horizontal vs vertical structure lines yielded no systematic difference in detection performance. Conclusions regarding the effects of the position of the structure lines might best be

withheld until this can be evaluated relative to individual search pattern preferences. The possibility that individual strategies may interact with specific structure characteristics seems worthy of further investigation.

Summary

The effects of amount of structure of the visual field on target detection were investigated for target durations of 5, 10, 20 and 40 seconds. The search area varied in structure from 0 (darkness) to a restricted 4 x 4 ft. area divided into 2, 4, 8, and 16 equal partitions by use of either vertical or horizontal lines. Sixty-four undergraduate Ss searched for 10 low visibility targets under each of 7 structure conditions.

The results suggested an optimal amount of structure at two bits (four partitions). Detection varied directly with target duration. In addition, differential effects of structure at various target durations suggested that the relative enhancement of detection through use of structure depends importantly on the target duration.

No significant difference was found in a comparison of horizontal vs vertical structure lines. However, conclusions regarding this variable might best be withheld until its effects can be evaluated relative to individual search pattern preferences.

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Appendix A

Instructions

Totally dark room

This is an experiment involving visual search. Your task is to detect a small point of light called a target. When you think you have seen a target, simply press the button that you are holding. Press the button only once for each target you detect. Be sure you actually see a target before you respond. The targets may appear anywhere in front of you, left or right, high or low. Your job is to maintain a constant search of the entire area in order to detect as many targets as possible. Targets will not occur in back of you nor directly overhead. (Questions?)

Point source of red light

There is now a small red light in front of you. This light will remain on. Your task remains the same. (Questions?)

Search area defined by projected slides

You now see a square area divided by grid lines. All targets will fall inside the perimeter of this figure. Your task remains the same. (Questions?)

No instructions were given as to how to search under any condition, only that a constant search was essential.

Appendix B

Table 2

Means and Standard Deviations of Percent Targets Detected for each Treatment Combination

		Vertical			Horizontal	
		Mean	Std. Dev.		Mean	Std. Dev.
	D	24	1.46	D	21	1.99
	L	23	.98	L	19	1.00
	0	20	.71	0	23	.68
5 sec.	1	19	.52	1	23	.98
	2	25	.87	2	17	1.54
	3	17	1.05	3	23	.68
	4	13	.90	4	10	1.00
	D	45	.50	D	40	1.41
	L	43	.71	L	47	1.76
	0	51	1.83	0	45	1.87
10 sec.	1	53	1.51	1	49	1.06
	2	51	1.54	2	57	1.41
	3	50	.71	3	55	1.80
	4	47	1.47	4	37	1.52
	D	51	1.97	D	59	1.35
	L	60	1.50	L	61	1.78
	0	63	1.89	0	67	1.37
20 sec.	1	76	1.69	1	71	1.40
	2	74	1.17	2	80	1.33
	3	75	2.00	3	73	1.10
	4	63	1.82	4	57	1.50
	D	79	1.57	D	76	1.69
	L	81	1.23	L	77	1.57
	0	83	.78	0	80	1.73
40 sec.	1	81	1.66	1	80	1.23
	2	83	.33	2	85	.87
	3	81	1.13	3	84	.75
	4	84	.75	4	79	.98

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